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PHYSICAL AND CHEMICAL STRATIFICATION IN TWO HIGH ALTITUDE RESERVOIRS OF THE COLORADO RIVER BASIN

PUBLIC HEALTH SERVICE, DENVER, COLORADO

NOVEMBER 1963

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U. S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
Public Health Service
Bureau of State Services
Division of Water Supply and Pollution Control
Region VIII

Colorado River Basin Water Quality Control Project

November 1963

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PHYSICAL AND CHEMICAL STRATIFICATION IN TWO HIGH ALTITUDE RESERVOIRS OF THE COLORADO RIVER BASIN

I. INTRODUCTION

Impoundments of Colorado River Basin waters have in the past, and will continue in the future, to effect a considerable influence on the economy and sociological structures of the Colorado River Basin. In an area of extreme fluctuation in surface streamflow over the annual cycle, reservoirs provide a stable supply of water throughout the year. In addition, impoundments serve to equalize and improve the quality of water available for use particularly during the low streamflow seasons. High streamflows of relatively good water quality resulting from snowmelt are impounded and blended with streamflow from the remainder of the year generally of poorer chemical quality. Water withdrawls are greatest during the summer months as dictated by land irrigation requirements. Impoundments provide an ample supply of water of reasonably good quality having little quality variance, and much improved over the nonregulated or natural conditions.

An understanding of thermal-stratification within an impoundment is necessary to predict water quality conditions of the storage water and also to predict the quality of water available in downstream areas. In the event of stratification the level of withdrawal may greatly influence the character of waters released. Each reservoir has particular characteristics in respect to stratification and it is important to realize this phenomena and its effects on changes of water quality.

This report contains physical and chemical data collected from study of two selected reservoirs of the Colorado River Basin. Little data is available relating to thermal and chemical stratification of impoundments in the Western United States and in particular, the Colorado River Basin.

The data to be collected from the investigation of reservoirs in addition to providing general information on stratification phenomena, promised to aid in Project evaluation of low-flow augmentation in conjunction with proposed Bureau of Reclamation reservoirs within the Colorado River Basin. Improvement of water quality in areas downstream from these reservoirs would possibly be suggested from the results of these studies.

The two reservoirs selected for study in August 1962 were Lake Granby located on the uppermost Colorado River in northern Colorado, and Taylor Park Reservoir in west-central Colorado on the headwaters of the Gunnison River, a major tributary to the Colorado River. Both reservoirs are situated near the top of the Continental Divide. The information obtained from the August 1962 studies was expected to show minimum stratification conditions existing for these two high-elevation reservoirs. This is in contrast to the far more pronounced stratification which was expected to be found in lower Colorado River Basin impoundments by the later investigations.

II. SUMMARY AND CONCLUSIONS

The field investigations of August 1962 for Lake Granby and Taylor Park Reservoir were intended to provide general information on stratifica-

tion phenomena in reservoirs of the Colorado River Basin, to aid in Project evaluation of low-flow augmentation by proposed reservoirs in the Basin, and promote an understanding of methods of improving water quality downstream from these reservoirs.

Data were collected for temperature, dissolved oxygen, 5-day BOD, conductivity, alkalinity, pH, Secchi Disk readings, and plankton enumeration of the main lake, and inflow and outflow waters. Radiological content of bottom lake muds was also determined.

Thermal stratification was a borderline condition observed in both water bodies during August 1962. The region of thermocline in Lake Granby exhibited a temperature gradient of 1.4°C per meter of depth and that in Taylor Park Reservoir approximated 1.1°C per meter of depth. An arbitrary standard of 1.0°C per meter of depth is generally recognized as the minimum temperature gradient necessary in formation of a thermocline and stratification. The thermocline was established between the 25 and 50 foot depths in both Lake Granby and Taylor Park Reservoir. The field data for temperature and dissolved oxygen showed uniformity in conditions for all stations at equal sampling depths. The familiar S-curves for temperature and dissolved oxygen under stratification conditions were found for both impoundments. Average temperatures in the epilimnion zone of Lake Granby ranged from 15.8 to 17.3°C and dissolved oxygen values from 7.5 to 8.1 mg/l. Hypolimnion waters demonstrated average temperatures of 6.5 to 8.7°C and dissolved oxygen content from 5.0 to 5.6 mg/l. Comparable values for Taylor Park Reservoir were: epilimnion-14.0 to 15.3°C temperature, and 7.1 to 7.4 mg/l dissolved oxygen; hypolimnion-6.1 to 7.8°C temperature, and 6.0 to 6.2 mg/l dissolved oxygen.

These reservoirs do not exhibit drastic depletion of dissolved oxygen in the lower waters bacause the levels of organic material are minimal and the period of stratification is relatively short at these high elevations. The average BOD level of waters in both impoundments were less than 1.0 mg/l and these waters are considered to be oligotrophic in nature. Conductivity and alkalinity values were extremely low and further were uniform in the vertical and horizontal directions throughout both reservoirs. Bottom sediments for both Lake Granby and Taylor Park Reservoir contained relatively high radioactivity levels. Gross alpha counts were about 3 times higher and radium levels approximately 1.5 times the average levels found in river bottom sediments of natural background. Moderate plankton densities were found in both Lake Granby and Taylor Park Reservoir and there appeared to be no quantitive difference between surface and bottom waters.

III. DESCRIPTION OF RESERVOIRS UNDER STUDY

The two reservoirs selected for study are both located within the Upper Main Sub-Basin, one of the six main subdivisions previously established by the Project for the Colorado River Basin. A location map of the two impoundments in reference to the Upper Main Stem Sub-Basin is shown in Figure 1.

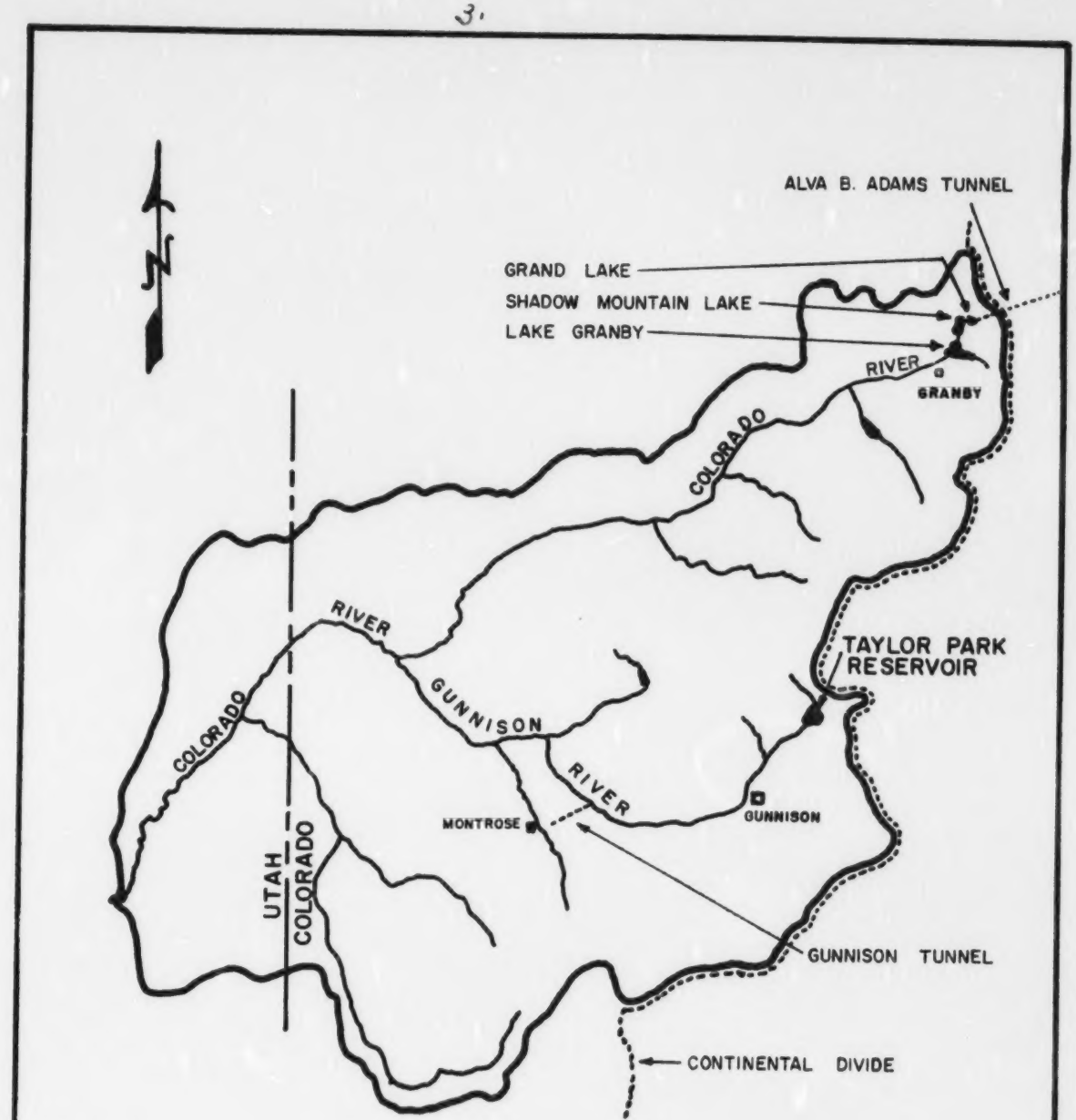

ALVA B. ADAMS TUNNEL
GRAND LAKE
SHADOW MOUNTAIN LAKE
LAKE GRANBY
RIVER
GRANBY
COLORADO
RIVER
TAYLOR PARK RESERVOIR
COLORADO
GUNNISON
RIVER
MONTROSE
GUNNISON
UTAH
COLORADO
GUNNISON TUNNEL
CONTINENTAL DIVIDE
SCALE - MILES
0 10 20 30 40 50
COLORADO RIVER BASIN
WATER QUALITY CONTROL PROJECT
UPPER MAIN STEM
SUB-BASIN
DEPT. OF HEALTH, EDUCATION, & WELFARE
PUBLIC HEALTH SERVICE
REGION VIII DENVER, COLORADO

FIGURE 1

A. Lake Granby

Lake Granby is on the headwaters of the Colorado River a few miles northeast of the town of Granby, Colorado and near Rocky Mountain National Park. It lies partially within the Arapaho National Forest, and wholly within the Shadow Mountain Recreation Area maintained by the National Park Service. Lake Granby is the lowermost unit of three impoundments in series on the headwaters of the Colorado River, all part of the Colorado-Big Thompson, U. S. Bureau of Reclamation Project. Grand Lake and Shadow Mountain Reservoir are located immediately upstream of Lake Granby.

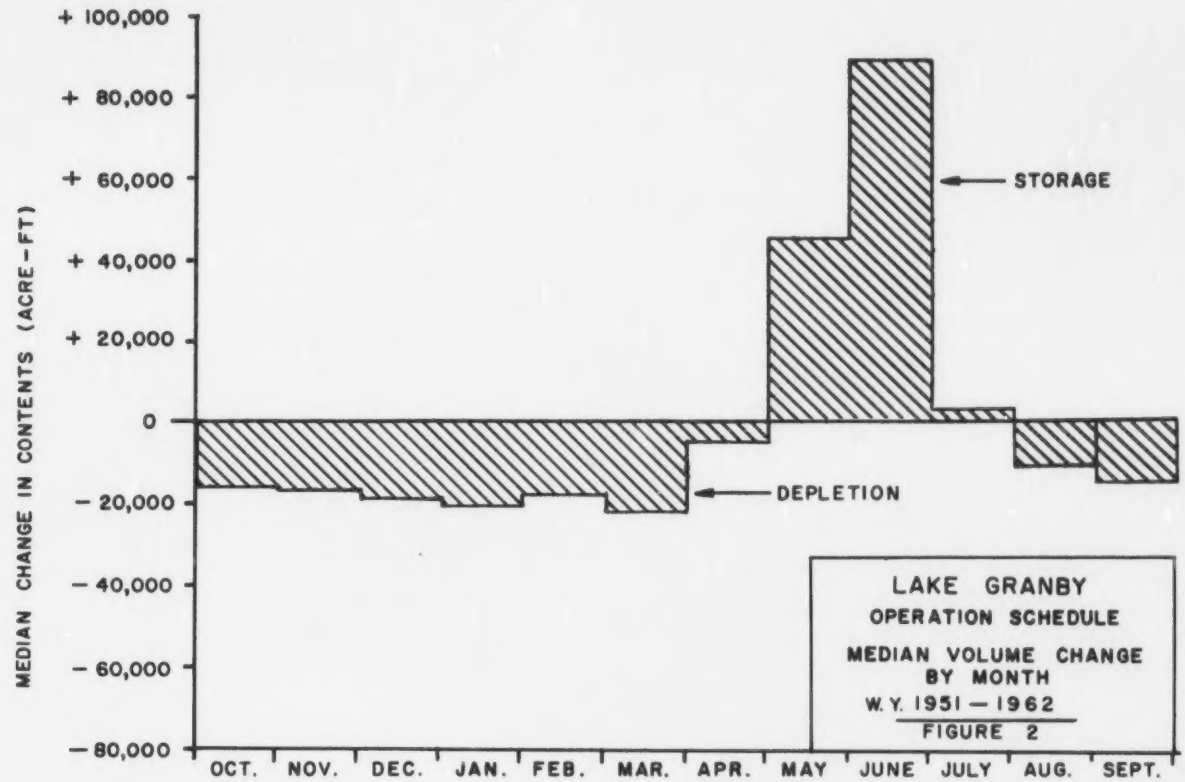
Lake Granby stores the majority of water supply for the Colorado-Big Thompson Project and is formed by Granby Dam from waters of the Colorado River, numerous creeks, and water pumped from Willow Creek Reservoir approximately 18 miles to the west. Lake Granby was constructed in 1941-1949 by the U. S. Bureau of Reclamation as part of the Colorado-Big Thompson Project. In connection with this Project, water stored in Lake Granby is pumped to Shadow Mountain Reservoir in times of demand, thereby flows into Grand Lake and thence is directed into the Alva B. Adams tunnel below the Continental Divide for transport to the eastern slope of the Rockies and the plains beyond. This water is used for recreation while in the reservoirs, for power generation on its descent down the eastern slope and ultimately for irrigation of large tracts of land in northeastern Colorado. The remainder of impounded waters of Lake Granby not diverted to the Colorado-Big Thompson Project are released from Granby Dam to reform the Colorado River (1).

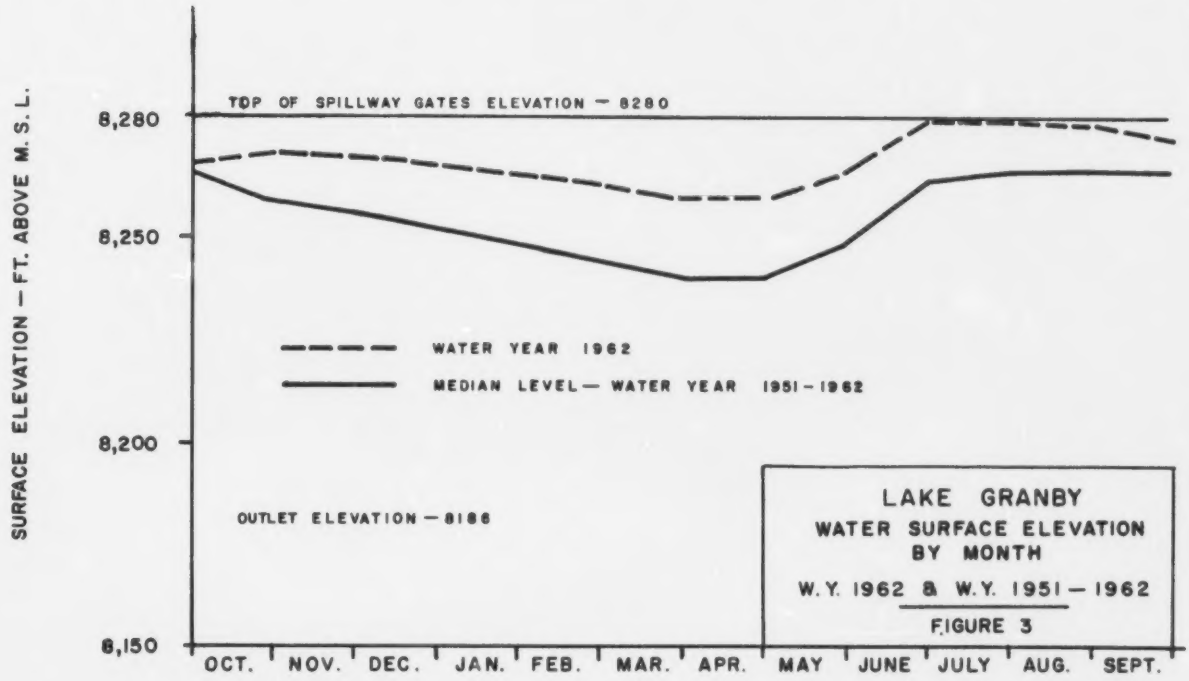
Lake Granby has a maximum capacity of 540,000 acre-feet and active storage of 466,000 acre-feet. The lake at maximum capacity covers a surface area of 7,260 acres and has average and maximum depths of 74 and 200 feet, respectively. Maximum water surface elevation is 8,280 feet above mean sea-level. The outlet at the face of Granby Dam is set between elevations 8150 and 8190 feet but active storage is considered to extend downward to elevation 8186 feet giving a maximum drawdown head of 94 feet. The outlet at Grandby Dam is regarded to be an intermediate to low-level takeoff. The average annual inflow to the Lake Granby site for the period 1920-1947 was 102,700 acre-feet. Calculation of average detention time of impounded water within the reservoir is somewhat fallacious under the operational conditions maintaned. However, the actual storage time of water released to the Colorado River is considerably long, measured in terms of a few years, judging from U. S. Geological Survey information on quantities of inflow and outflow (1, 2, 3).

Lake Granby, as shown by Figure 2, annually receives the majority of storage water during the heavy runoff months of May and June. It should be noted according to Figure 3 that storage during Water Year 1962 was appreciably above the median storage for the period of record, 1951-1962. The reservoir was very near full capacity during the field survey of August 1962 (2, 3).

B. Taylor Park Reservoir

Taylor Park Reservoir is on the head of Taylor River, one of two streams (Taylor and East Rivers) which form the headwaters of the Gunnison


+ 100,000
+ 80,000
+ 60,000
+ 40,000
+ 20,000
0
- 20,000
- 40,000
- 60,000
- 80,000
MEDIAN CHANGE IN CONTENTS (ACRE-FT)
STORAGE
DEPLETION
OCT.
NOV.
DEC.
JAN.
FEB.
MAR.
APR.
MAY
JUNE
JULY
AUG.
SEPT.
LAKE GRANBY
OPERATION SCHEDULE
MEDIAN VOLUME CHANGE
BY MONTH
W.Y. 1951 — 1962
FIGURE 2


SURFACE ELEVATION — FT. ABOVE M.S.L.
TOP OF SPILLWAY GATES ELEVATION — 8280
8,280
8,250
8,200
8,150
WATER YEAR 1962
MEDIAN LEVEL — WATER YEAR 1951 - 1962
OUTLET ELEVATION — 8186
OCT.
NOV.
DEC.
JAN.
FEB.
MAR.
APR.
MAY
JUNE
JULY
AUG.
SEPT.
LAKE GRANBY
WATER SURFACE ELEVATION
BY MONTH
W.Y. 1962 & W.Y. 1951 — 1962
FIGURE 3

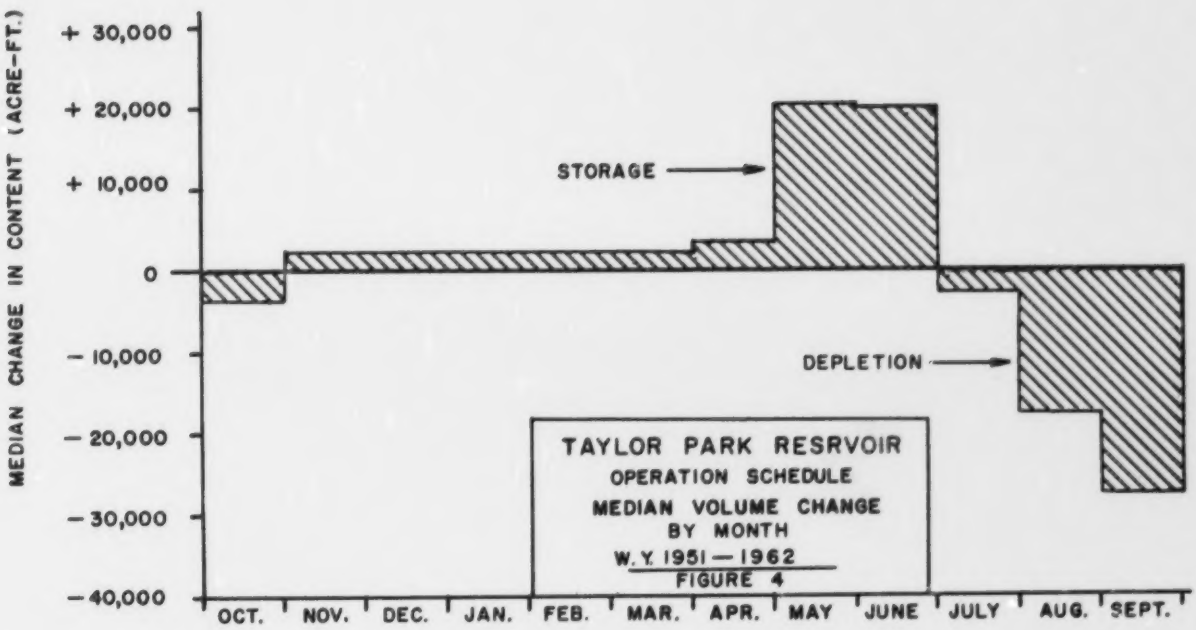
River in west-central Colorado. The reservoir is approximately 12 miles northeast of the town of Gunnison, Colorado and within the boundaries of the Gunnison National Forest. Taylor Park Reservoir was constructed in 1935-1937 by the U. S. Bureau of Reclamation as part of the Uncompahgre Project. This impoundment stores spring run-off from the Taylor River watershed for supplementation of low streamflow in the Gunnison River during the summer months. The majority of available streamflow of the Gunnison River during the summer is diverted through the Gunnison Tunnel to 75,000 acres of irrigated land in the Uncompahgre River Valley in the area between Montrose and Delta, Colorado. The Gunnison Tunnel Diversion is approximately 80 river miles below Taylor Park Reservoir and 12 miles due east from the town of Montrose, Colorado (1).

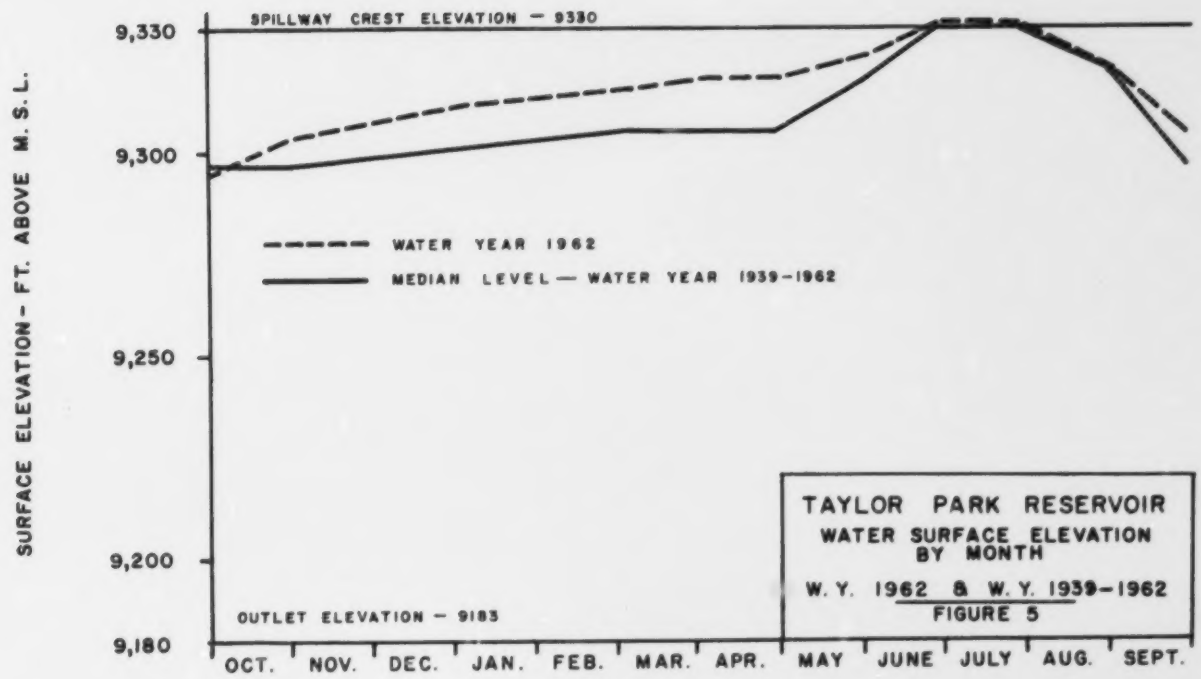
Taylor Park Reservoir has a maximum capacity of 106,000 acre-feet with no inactive storage. The lake at full capacity covers a surface area of 2,040 acres and has average and maximum depths of 52 and 147 feet, respectively. Maximum water surface elevation is 9330 feet above mean sea-level. The minimum elevation of the outlet structure on the dam face is 9183 feet giving a maximum drawdown head of 147 feet. The outlet at Taylor Park Dam is considered to be a low-level take-off. Average annual inflow into Taylor Park Reservoir over the period 1939-1950 was 137,050 acre-feet (1).

Figure 4 shows the operational schedule of Taylor Park Reservoir. The majority of water is impounded during the heavy runoff months of May and June. Large amounts of supplemental water are added to the normal streamflow of the Gunnison River for irrigational use in the Uncompahgre River Valley beginning in July and continuing through late September or early October. It is evident from Figure 4 that average detention time of water within Taylor Park Reservoir approximates 4 months. The information given by Figure 5 shows that storage in Water Year 1962 was significantly above the median storage for the period of record, 1939-1962. The reservoir was full with some spillway overflow during July and the early part of August 1962. The reservoir was very near maximum storage capacity during the field survey of Taylor Park Reservoir in mid-August of 1962 (1,2,3).

IV. CONDUCT OF SURVEY

This report considers field investigations undertaken in August 1962 to determine physical and chemical stratification in two reservoirs located at high elevations in the upper portion of the Colorado River Basin. The study of Lake Granby was conducted during August 22-24, 1962 and the Taylor Park Reservoir phase of investigations was undertaken during August 15-16, 1962. Two engineers were employed for sampling and one chemist was also available to perform the analytical determinations necessary in the field. Samples from the main part of Lake Granby were taken from a 35-foot boat owned by the National Park Service and operated by personnel from that agency. Samples from the main part of Taylor Park Reservoir were taken from a 15-foot Project boat operated by Project personnel. Main-lake sampling locations were approximated from significant landmarks on the shore. Lake inflows and outflows were sampled by hand from accessible shores and bridges.


MEDIAN CHANGE IN CONTENT (ACRE-FT.)
+ 30,000
+ 20,000
+ 10,000
0
- 10,000
- 20,000
- 30,000
- 40,000
STORAGE
DEPLETION
OCT.
NOV.
DEC.
JAN.
FEB.
MAR.
APR.
MAY
JUNE
JULY
AUG.
SEPT.
TAYLOR PARK RESRVOIR
OPERATION SCHEDULE
MEDIAN VOLUME CHANGE
BY MONTH
W. Y. 1951 — 1962
FIGURE 4


SURFACE ELEVATION - FT. ABOVE M. S. L.
SPILLWAY CREST ELEVATION — 9330
9,330
9,300
9,250
9,200
9,180
WATER YEAR 1962
MEDIAN LEVEL — WATER YEAR 1939-1962
OUTLET ELEVATION — 9183
OCT.
NOV.
DEC.
JAN.
FEB.
MAR.
APR.
MAY
JUNE
JULY
AUG.
SEPT.
TAYLOR PARK RESERVOIR
WATER SURFACE ELEVATION
BY MONTH
W. Y. 1962 & W. Y. 1939-1962
FIGURE 5

Physical and chemical determinations for main-lake sampling included water temperature readings taken at the lake surface, 5 and 10 feet depths and thereafter at 10 foot intervals until reaching the lake bottom. A Yellow Springs tele-thermometer equipped with thermister and extension probe of 210 feet provided the necessary temperature readings for this study. Dissolved oxygen determinations were generally made at the lake surface, 10, 20, and 30 feet depths and thereafter most often at 20 foot intervals to the lake bottom. Five-day Biochemical Oxygen Demand[1/] results were obtained at various depths but most frequently at the surface, mid-lake depth and near the lake bottom. Water samples were collected at various depths in the Lake by means of a 2-liter Kemmerer water bottle sampler. Secchi Disk readings were made at each lake station. Specific conductance (adjusted to 25°C) alkalinity and pH determinations were made but only a limited number were necessary for control purposes since these values were relatively constant from lake surface to bottom. All analytical procedures were performed according to "Standard Methods" (4). Secchi Disk recordings were obtained in accordance with recognized limnological methods (5). All physical and chemical measurements were made at the site of investigation except for BOD analyses which were performed at a Project laboratory temporarily located in Montrose, Colorado for purposes of another survey.

In addition to physical and chemical measurements, a limited number of bottom lake sediments were collected for subsequent radioactivity analyses, and also plankton studies consisting of plankton enumeration of surface and bottom lake waters were conducted at selected main lake stations. Radiological and plankton analyses were performed at the Project Laboratory in Salt Lake City.

Plankton determinations were undertaken at approximately one-half of the alke stations. One-gallon water samples were collected and preserved with sufficient formalin to provide a 5 percent concentration of preservative in sample. Two-liter portions of each sample were centrifuged through a continuous Foerst centrifuge and the precipitate made up to a volume of 20 ml. One milliliter of the precipitate solution was added to a Sedgewick-Rafter counting cell and a survey count of the whole cell made for zooplankton at 100X magnification. One strip, horizontally across the cell was then counted at 200X magnification for phytoplankton enumeration and identification.

Lake inflows and outflows were sampled at mid-depth and water quality data were obtained for temperature, dissolved oxygen, 5-day BOD, specific conductance, alkalinity and pH.

During the survey of Lake Granby, weather conditions on August 22 were partly cloudy but moderately warm. The morning of August 23 was clear. However, shortly after noon, moderate winds and overcast sky

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1/ BOD or biochemical oxygen demand is the quantity of oxygen, generally expressed in milligrams per liter, required for stabilization of decomposable organic matter by aerobic biochemical action. This test is generally carried out for 5 days at 20°C.

conditions had developed. Heavy rains commenced at 1300 hours and continued throughout the afternoon. The morning of August 24, on which the Lake Granby survey was completed, was clear but relatively cool.

Weather conditions for the survey of Taylor Park Reservoir through August 15 and the morning of August 16 wer partly cloudy and winds were moderate to strong. Thunderstorms with heavy rain were experienced from 1300 to 1500 hours on August 16 and overcast skies were present throughout the remainder of this day.

The location of sampling stations employed for the Lake Granby survey of August 22-24, 1962 are shown on a small scale map of the lake in Figure 6. Detail on description of these sampling locations is given in Table 1.

The location of sampling points utilized during the field investigations of August 15-16 of Taylor Park Reservoir are illustrated on a small scale map of the lake in Figure 7. Further information on description of these sampling stations is compiled in Table II.

V. PRESENTATION AND DISCUSSION OF DATA

A.. Lale Granby

1. Temperature and Dissolved Oxygen

Temperature and dissolved oxygen results obtained for Lake Granby are shown respectively in Tables III and IV. Temperature and dissolved oxygen in relation to depth as an average of conditions experienced for Stations GB-2, GB-3, GB-6, and GB-8, the latter representing locations of greatest depth in the lake proper, are illustrated in Figure 8. Dissolved oxygen saturation as a function of depth, averaged for the four primary stations above is given by Figure 9. A brief treatise on stratification principles, theory and terminology within lakes and reservoirs pertinent to the following discussion on Lake Granby and Taylor Park Reservoir is given in Appendix B.

Within Lake Granby there was little variation at equal depths for temperature and dissolved oxygen conditions at the various sampling stations. In addition to uniformity at given levels throughout the lake body, this data indicated that density currents were not observed at any point in the reservoir. The temperature and dissolved oxygen curves of Figure 8 show a definite stratification of Lake Granby waters and three distinct zones of circulation. The waters of the upper 25 feet were relatively constant in temperature and dissolved oxygen content. This relatively warm, oxygen abundant upper layer is termed the epilimnion or well-mixed zone. Wind action is effective in providing circulation of this water and heating is applied from above by solar radiation. Average temperatures ranged from 15.8 to 17.3°C and dissolved oxygen content from 7.5 to 8.1 mg/l in this upper zone. The dissolved oxygen levels in the epilimnion of Lake Granby all exceeded saturation and ranged from 103 to 113 percent of saturation value.

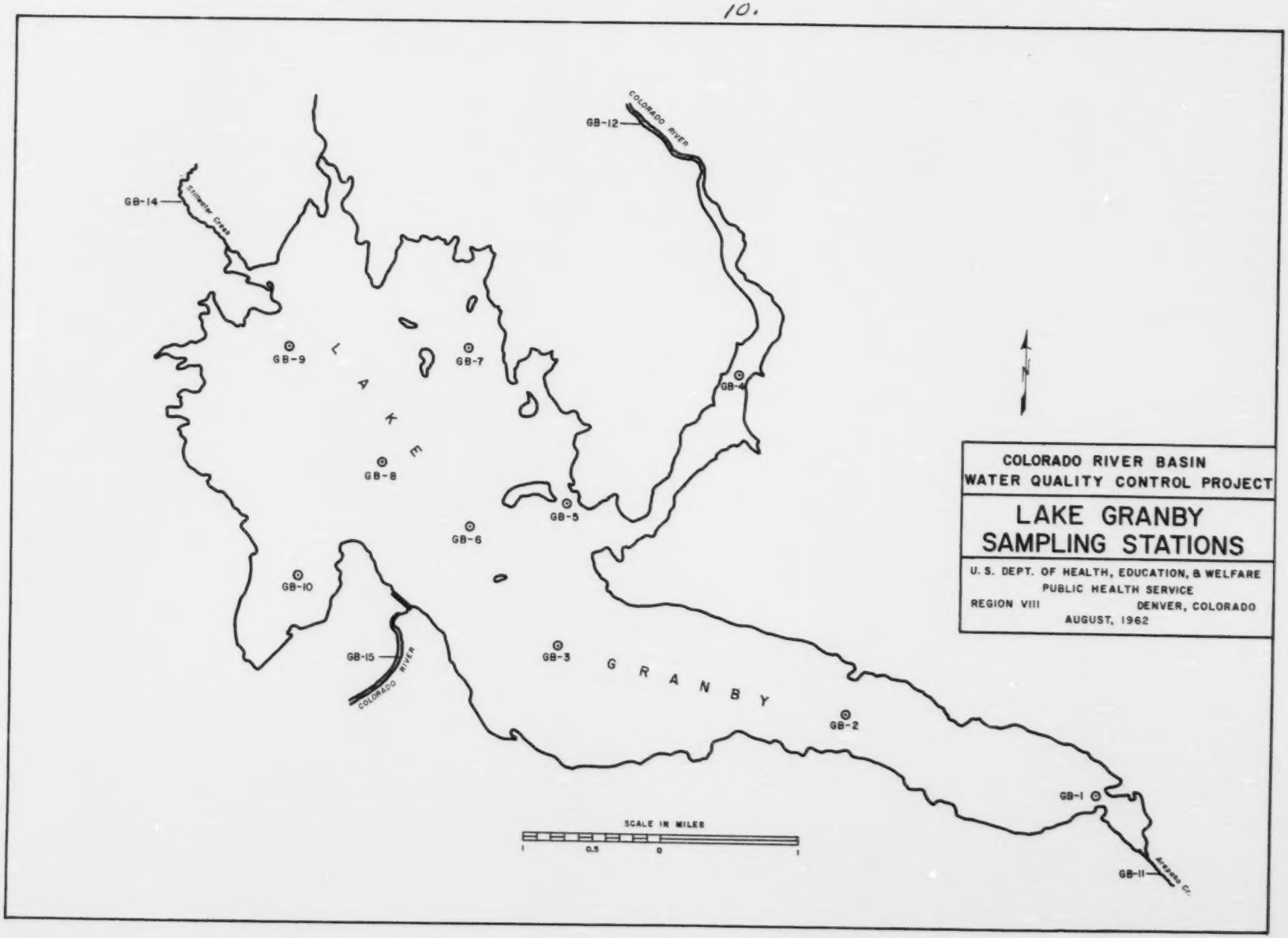
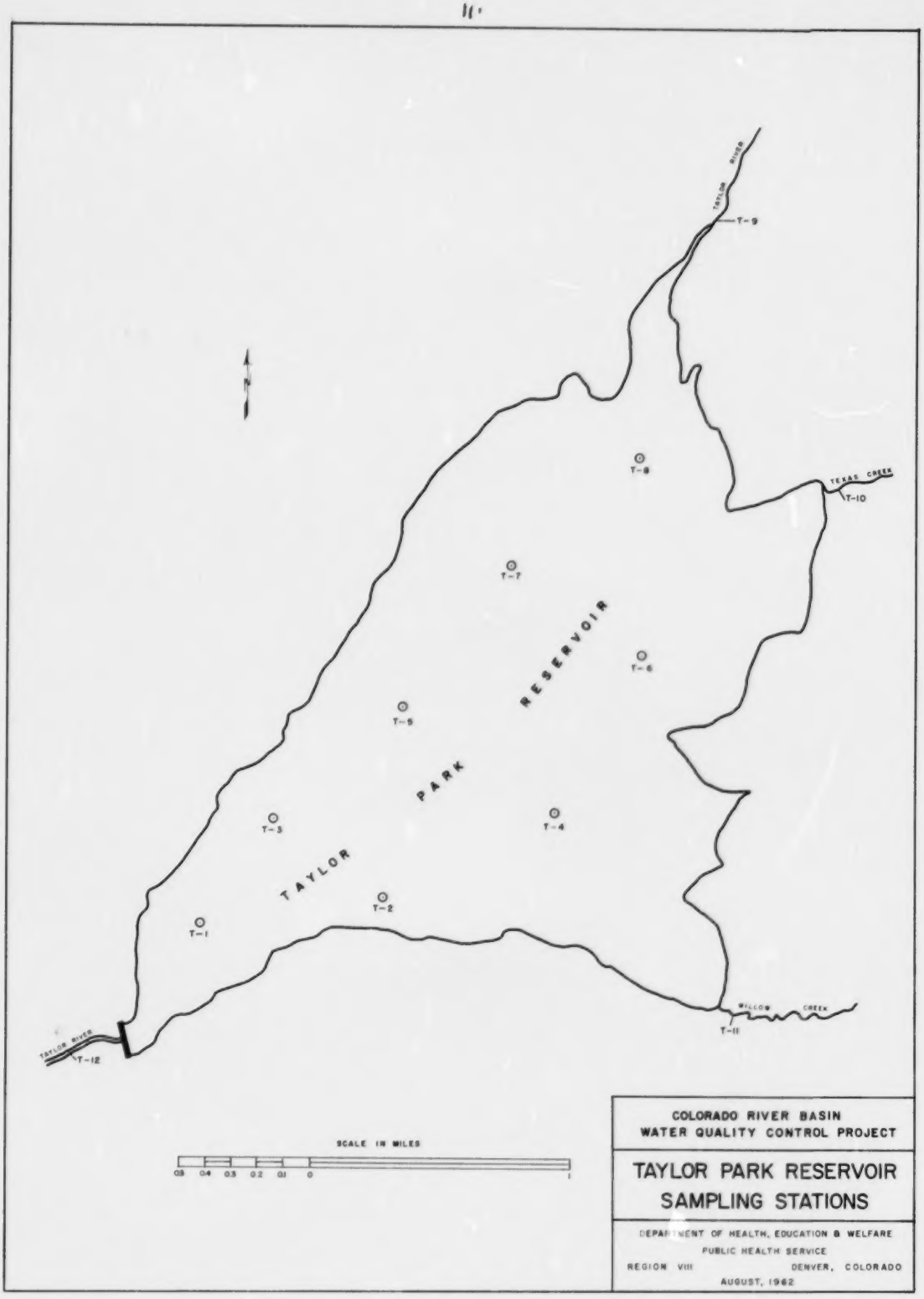

COLORADO RIVER
GB-12
GB-14
Stillwater Creek
GB-9
GB-7
GB-4
L A K E
GB-8
GB-5
GB-6
GB-10
GB-15
COLORADO RIVER
GB-3
G R A N B Y
GB-2
GB-1
GB-11
Arapaho Cr.
SCALE IN MILES
1 0.5 0 1
N
COLORADO RIVER BASIN
WATER QUALITY CONTROL PROJECT
LAKE GRANBY
SAMPLING STATIONS
U. S. DEPT. OF HEALTH, EDUCATION, & WELFARE
PUBLIC HEALTH SERVICE
REGION VIII DENVER, COLORADO
AUGUST, 1962

FIGURE 6



COLORADO RIVER BASIN
WATER QUALITY CONTROL PROJECT

TAYLOR PARK RESERVOIR SAMPLING STATIONS

DEPARTMENT OF HEALTH, EDUCATION & WELFARE
PUBLIC HEALTH SERVICE
REGION VIII DENVER, COLORADO
AUGUST, 1962

FIGURE 7

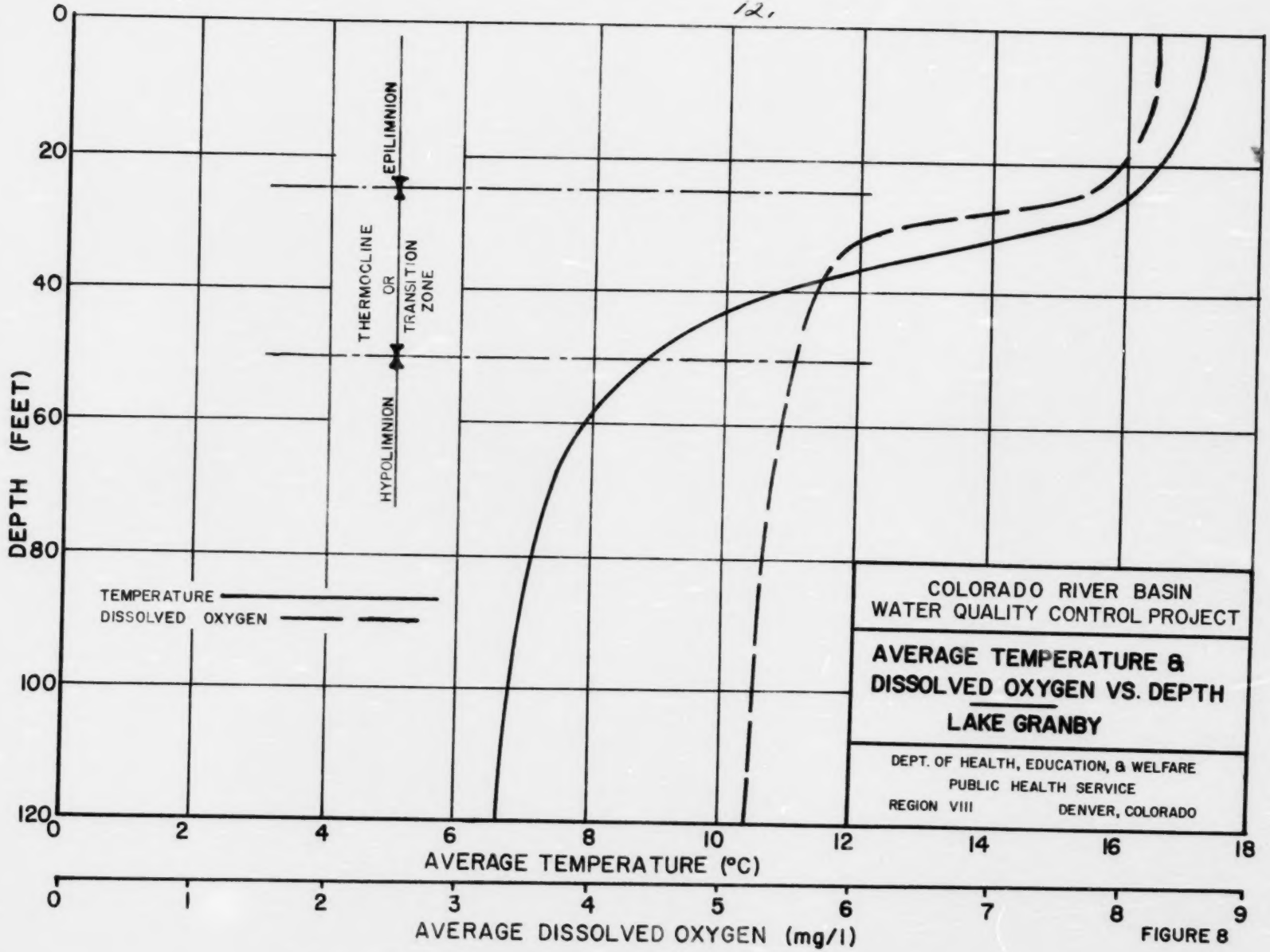

DEPTH (FEET)
0
20
40
60
80
100
120
EPILIMNION
THERMOCLINE OR TRANSITION ZONE
HYPOLIMNION
TEMPERATURE
DISSOLVED OXYGEN
0
2
4
6
8
10
12
14
16
18
AVERAGE TEMPERATURE (°C)
0
1
2
3
4
5
6
7
8
9
AVERAGE DISSOLVED OXYGEN (mg/l)
COLORADO RIVER BASIN
WATER QUALITY CONTROL PROJECT
AVERAGE TEMPERATURE & DISSOLVED OXYGEN VS. DEPTH
LAKE GRANBY
DEPT. OF HEALTH, EDUCATION, & WELFARE
PUBLIC HEALTH SERVICE
REGION VIII
DENVER, COLORADO

FIGURE 8

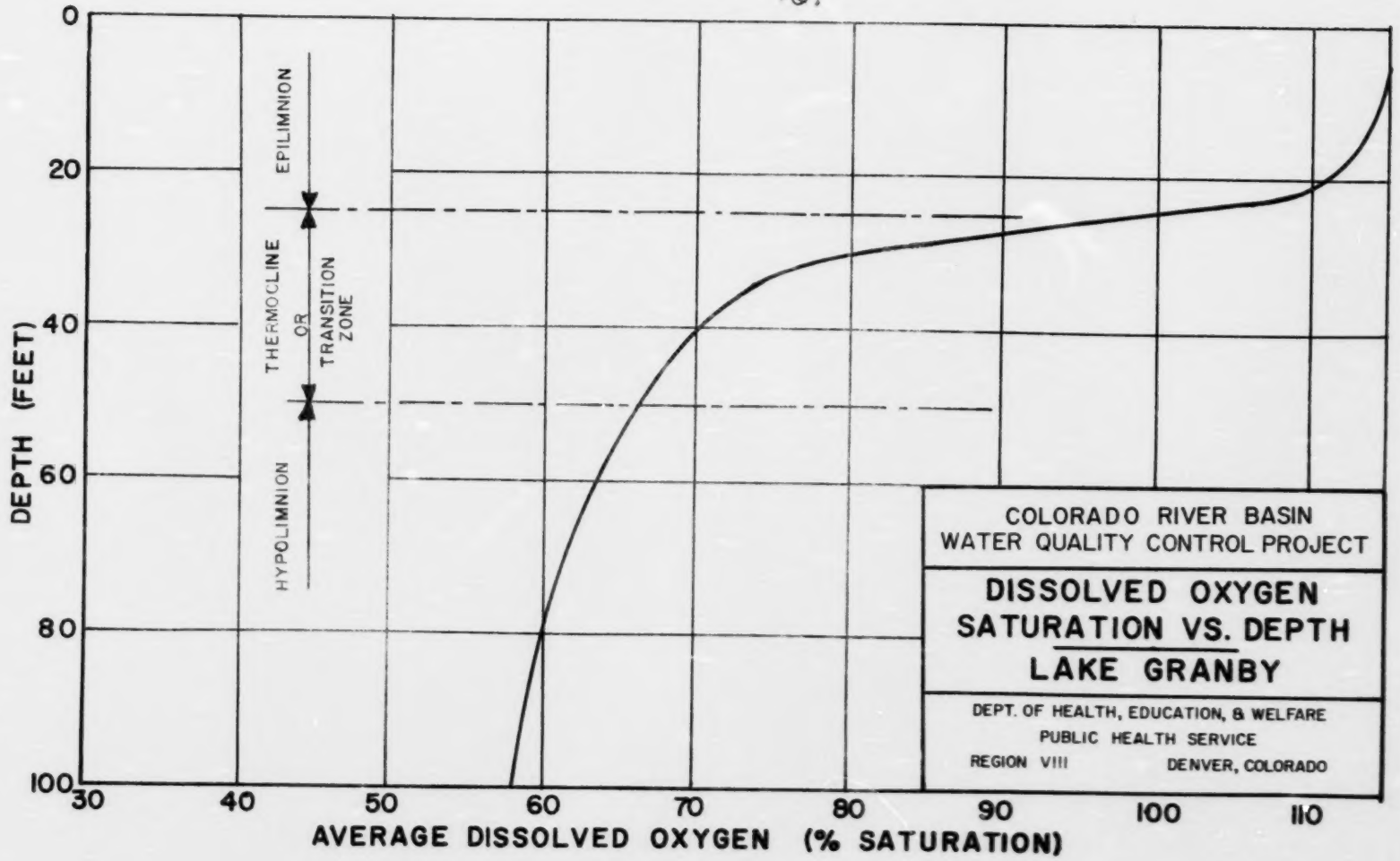

0
20
40
60
80
100
DEPTH (FEET)
EPILIMNION
THERMOCLINE
OR
TRANSITION
ZONE
HYPOLIMNION
30
40
50
60
70
80
90
100
110
AVERAGE DISSOLVED OXYGEN (% SATURATION)
COLORADO RIVER BASIN
WATER QUALITY CONTROL PROJECT
DISSOLVED OXYGEN
SATURATION VS. DEPTH
LAKE GRANBY
DEPT. OF HEALTH, EDUCATION, & WELFARE
PUBLIC HEALTH SERVICE
REGION VIII
DENVER, COLORADO

FIGURE 9

TABLE I
Sampling Stations for Lake Granby Study
August 22-24, 1962

Station	Description
GB-1	Main Lake; southeast end of lake near Roaring Fork Ranger Station in center of channel.
GB-2	Main Lake; southeast arm of lake near "Twin Pines Point," midway between shores.
GB-3	Main Lake; directly east of Dam near center of lake.
GB-4	Main Lake; 1.7 miles up Colorado River arm of lake.
GB-5	Main Lake; near inlet of Colorado River arm of lake.
GB-6	Main Lake; midway between Dam and Colorado River arm of lake in center of lake.
GB-7	Main Lake; north side of lake approximately 0.5 miles from shore and 1.8 miles west of Colorado River arm of lake.
GB-8	Main Lake; approximately 1.1 miles north-northwest of Dam.
GB-9	Main Lake; northwest corner of lake 0.8 miles from Stillwater Creek inlet to lake.
GB-10	Main Lake; in southwest arm of lake.
GB-11	Arapaho Creek inflow from road bridge crossing at southeast tip of lake, and 1.2 miles downstream from Monarch Lake.
GB-12	Colorado River inflow from road bridge crossing, 0.15 miles below Shadow Mountain Lake and 1.0 miles upstream from Pole Creek.
GB-14	Stillwater Creek inflow from road 0.8 miles upstream of inlet into lake.
GB-15	Colorado River outflow from Dam, from road bridge crossing, 1.1 miles below Dam.

TABLE II
Sampling Stations for Taylor Park Reservoir Study
August 15-16, 1962

Station	Description
T-1	Main Lake; over original channel of Taylor River, approximately midway between east and west shores, 0.5 miles above Dam.
T-2	Main Lake; south side of lake approximately 0.15 miles from shore and 1.1 miles above Dam.
T-3	Main Lake; over original channel of Taylor River near northwest shore 1.0 miles above Dam.
T-4	Main Lake; southeast corner of lake, approximately 2.0 miles above Dam.
T-5	Main Lake; over original channel of Taylor River near northwest shore 1.7 miles above Dam.
T-6	Main Lake; east side of lake approximately 2.5 miles above Dam.
T-7	Main Lake; over original channel of Taylor River 0.4 miles from northwest shore and approximately 2.3 miles above Dam.
T-8	Main Lake; north end of lake near inlet of Taylor River arm of lake.
T-9	Taylor River inflow from road approximately 0.3 miles above entry to lake.
T-10	Texas Creek inflow from road bridge crossing, 0.5 miles above entry to lake.
T-11	Willow Creek inflow from road bridge crossing, 0.6 miles above entry to lake.
T-12	Taylor River outflow from Dam, from road bridge crossing, 0.3 miles below Dam.

TABLE III
Lake Granby - Water Temperature (°C)

Depth (ft.)	Lake Stations									
	GB-1	GB-2	GB-3	GB-4	GB-5	GB-6	GB-7	GB-8	GB-9	GB-10
0	17.2	17.7	17.3	17.3	17.3	17.0	17.0	17.0	16.8	16.7
5	16.9	17.2	17.2	17.3	17.3	17.0	17.0	16.8	16.8	16.7
10	16.7	17.0	16.8	17.2	17.0	16.9	16.9	16.7	16.8	16.7
20	16.4	16.8	16.5	16.4	16.8	16.7	16.9	16.6	16.7	16.5
30		15.0	13.8	15.4	15.8	15.4	16.0	14.5	14.5	16.1
40		10.1	11.4	11.7	12.0	10.7	13.1	10.3	11.3	10.6
50		8.1	8.9	7.8	8.9	9.0	8.7	8.7	9.7	9.3
60		7.7	7.7	8.5		8.2		7.6	8.9	8.4
70		7.3	7.3	7.4		7.6		7.2	8.3	7.5
80		7.1	7.0			7.3		6.9		7.2
90		7.0	6.8			7.0		6.8		
100			6.7			6.9		6.6		
110			6.7			6.9		6.5		
120			6.6			6.8		6.5		
130						6.8		6.4		
140						6.8		6.4		
150						6.8				
160						6.8				
170						6.7				
180						6.7				
190						6.7				
200						6.6				

Depth (ft.)	Inflow and Outflow Stations			
	GB-11	GB-12	GB-14	GB-15
Surface	-	11.3	16.0	16.8

TABLE IV
Lake Granby - Dissolved Oxygen (mg/l)

Depth (ft.)	Lake Stations									
	GB-1	GB-2	GB-3	GB-4	GB-5	GB-6	GB-7	GB-8	GB-9	GB-10
0	8.0	8.1	8.1		8.1	8.1	8.3	8.0	8.0	8.2
10	8.1	8.3	8.2			8.2		8.3	7.9	8.1
20	7.0	8.0	8.1			8.1		8.2	7.9	8.1
25					7.2					
30		5.8	6.4			6.3		6.0	5.8	6.3
45							6.3			
50		5.8	6.0		5.6	5.9		5.7	4.5	5.4
60				3.5						
70			5.6			5.6		5.4		
75										4.7
80		5.1								
100						5.4		5.0		
105			5.1							
120						5.4		5.2		
150						5.4				
180						5.0				

Depth (ft.)	Inflow and Outflow Stations			
	GB-11	GB-12	GB-14	GB-15
Surface	7.2	7.8	9.8	8.5

The region extending from the 50 foot depth to the lake bottom can be termed the hypolimnion or stagnation zone. This zone is separated from the epilimnion during the warmer months by stratification in the transition zone or region of thermocline above. There is no interaction or mixing at this time of the year between waters of the epilimnion and hypolimnion and thus no heating nor renewal of oxygen resources of waters in the lower part of the reservoir. The waters of the hypolimnion have temperature levels approximating winter conditions and are progressively depleted of dissolved oxygen by organic material present throughout the period of stratification. It is common in many reservoirs that dissolved oxygen levels in hypolimnion waters may range between 0 and 2 mg/l and even intense anaerobic conditions may exist in the lowermost waters. Both Lake Granby and Taylor Park Reservoir do not exhibit drastic depletion of dissolved oxygen resources in the hypolimnion principally because the levels of decomposable organic material within the inflow and also found in the lake are exceptionally low, and secondly, the period stratification is relatively short at these high elevations. Average temperatures of hypolimnion waters of Lake Granby ranged from 6.5 to 8.7°C and dissolved oxygen ranged from 5.0 to 5.6 mg/l. These oxygen values were between 56 and 63 percent of saturation at the temperature recorded.

The transition zone or thermocline region separates the epilimnion from the hypolimnion by creating an effective barrier against wind action in penetrating this zone and preventing admixture of the two bodies of water. The energy required of wind action to destroy this zone of stratification generally is many times greater than that required to maintain complete circulation of epilimnion waters. This energy for effective mixing of various layers is directly proportional to the temperature gradient and the difference in density of the various layers to be admixed. Investigations are continuing at the U. S. Public Health Service facilities of the Taft Sanitary Engineering Center in Cincinnati, Ohio to determine the most effective and economical means by air diffusion or pumping to destroy the stratification barrier and thereafter maintain uniform quality conditions in large reservoirs.

The region of thermocline in Lake Granby extended between the 25 and 50 foot depth levels. A significant temperature decrease was experienced in this zone. The maximum temperature gradient was 1.4°C per meter of depth and the average temperature gradient between the 25 and 50 foot depths was 1.2°C meter of depth. A thermocline is generally considered to be present if the temperature gradient is equal to or greater than 1.0°C per meter of depth. Thermal stratification in Lake Granby during August 1962 was barely sufficient to meet minimum conditions for a thermocline but nevertheless the three distinct circulation zones did exist. Since the gradient was so small during this study, which was made during a period of the year when maximum stratification was to be expected, the temperature gradient during the remaining and colder months of the year would be reduced and would approach zero.

Average temperatures of waters in the transition zone of Lake Granby ranged from 8.7 to 15.8°C and dissolved oxygen content ranged

from 5.6 to 7.5 mg/1. Dissolved oxygen values were between 63 and 103 percent of saturation.

Temperature and dissolved oxygen results for the inflows into, and the outflow from Lake Granby showed that Arapaho Creek inflow (Station GB-11) had a lower water temperture than surface waters in the lake, whereas temperatures of Stillwater Creek inflow (Station GB-14) and the Colorado River outflow (Station GB-15) were comparable to that of surface waters in the lake. The temperature of water released from Granby Dam and thereby approximation of the level of withdrawal in the reservoir cannot be predicted from the field data. The Colorado River outflow (Station GB-15) was measured approximately 1 mile below the Dam and undoubtedly there was some increase in streamflow temperature over the intervening distance.

The dissolved oxygen of Arapaho Creek and the Colorado River inflows were near saturation whereas Stillwater Creek inflow and the Colorado River outflow waters were somewhat above saturation values.

2. Biochemical Oxygen Demand

Individual results of BOD content of Lake Granby waters are shown in Table VIII of Appendix A. A summary of this data indicates that BOD levels in the lake waters, inflows and outflow were very low. Lake samples taken at various depths for 10 stations ranged from 0.3 to 1.2 mg/1 in BOD content. Average BOD for Lake Granby samples was 0.7 mg/1. Surface lake waters were slightly higher in BOD content than bottom waters although this difference is not truly significant because of the extremely minimal levels of BOD in all samples. The inflows of the Colorado River, Arapaho and Stillwater Creeks contained low BOD content with a range of 1.1 to 1.7 mg/1 and the return waters to the Colorado River showed only 0.2 mg/1 5-day BOD.

The BOD information collected from Lake Granby indicates that lake waters and the tributary inflows contain very little organic material to cause depletion of dissolved oxygen within the reservoir. The moderate reduction of dissolved oxygen in the lower layers probably results from nonviable detritus which sinks to the bottom of the reservoir exerting an oxygen demand together with the lack of reoxygenation under stratification conditions. Due to a very low mineral content and nutrient level, Lake Granby may be classified as oligotrophic by nature.

3. Other Physical and Chemical Conditions for Lake Granby

Field data collected for conductivity, alkalinity, pH, and Secchi Disk reading for Lake Granby waters are given in Table VIII of Appendix A. Radioactivity results of bottom lake sediments for both Lake Granby and Taylor Park Reservoir are shown in Table V.

There was uniformity throughout Lake Granby both horizontally and vertically for total dissolved solids (as measured by conductivity) and for alkalinity content. These values which approximated 35 mg/1 for

TABLE V

Radioactivity of Lake Granby and
Taylor Park Reservoir Bottom Sediments

Station	Date	Depth (feet)	Gross Alpha (μμc/g) [a]	Radium-226 (μμc/g) [a]
A. Lake Granby				
GB-4	8-23-62	72	30	2.08
GB-5	8-23-62	52	21	1.59
GB-10	8-22-62	81	27	1.88
B. Taylor Park Reservoir				
T-3	8-16-62	112	31	1.96
T-4	8-16-62	52	13	0.86
T-8	8-16-62	33	36	2.54
Average			26	1.82

[a] gram dry weight

total dissolved solids (conductivity = 52 μmhos/cm) and 21 mg/l for alkalinity of lake water are the least values encountered in surface waters throughout the Colorado River Basin. Total dissolved solids and alkalinity of Colorado River inflow (Station GB-12) and outflow (Station GB-15), and Arapaho Creek (Station GB-11) approximated that in the lake body whereas Stillwater Creek water (Station GB-14) contained approximately 160 mg/l total dissolved solids and 110 mg/l alkalinity.

Levels of pH in the main lake decreased with increase in depth. Surface waters ranged from 8.5 to 8.9 in pH value whereas bottom waters ranged from 7.5 to 8.3 in terms of pH. Colorado River inflow and Arapaho Creek waters had respective pH values of 7.9 and 7.6. Stillwater Creek inflow and Colorado River outflow were respectively 9.1 and 9.3 in terms of pH.

The Secchi Disk reading is a measure of transparency or the light transmission properties of a water. Depths at which the Secchi Disk was indiscernable in Lake Granby waters ranged from 7.5 to 14 feet with a mean of 11 feet. These readings indicate that the lake waters were relatively clear and light transmission characteristics were good. Secchi Disk values for many midwest and eastern lakes are in the range of 3 to 8 feet. The relatively high values obtained for Lake Granby are in the order to be expected for high-elevation and clear mountain lakes receiving the majority of annual storage as spring runoff from snowmelt.

Radiological data for bottom lake sediments were collected in Lake Granby during August 22-23, 1962 and Taylor Park Reservoir during August 16, 1962 and are shown in Table V. Data from these lakes are treated together since radioactivity levels at the two locations were remarkably similar. These values, although few in number, show some unexpectedly high radioactivity levels in muds of Lake Granby and Taylor Park Reservoir. It was originally expected that radioactivity levels of bottom muds in Lake Granby and Taylor Park Reservoir would be relatively low and closely approximated natural conditions. The Project has previously found that radioactivity of natural or background river sediments approximate 9.0 μμc/g gross alpha content with a range in values of 3 to 13 μμc/g, and an average radium content of 1.1 μμc/g with a range in values of 0.6 to 2.1 μμc/g (6). The results of limited radiological investigations of Lake Granby and Taylor Park Reservoir in August 1962 show that these lake sediments contained above 3 times the level of gross alpha and slightly more than 1.5 times the radium level generally found in river bottom sediments of natural background. The reasons for the relatively high value are not known and although the limited number of results are not truly significant, some continuation of study in this regard is indicated.

4. Plankton Studies

The results of plankton analyses of surface and bottom water samples collected from the main part of Lake Granby are shown in Table X of Appendix C. Moderate numbers of plankton organisms were found in Lake Granby waters and in addition, there was little difference in plankton density between surface and bottom waters. Total phytoplankton counts ranged from a low of 71 organisms per liter in the sample collected

at the 120 foot depth at Station GB-8, to a maximum of 504 organisms per liter of the 105 foot depth sample collected at Station GB-3. The majority of phytoplankton consisted of blue-greens and diatoms, and there were very few flagellates. Rather large numbers of the blue-green algae, Oscillatoria, were found in surface water samples. This filamentous form in sufficient numbers can produce an undesirable matting effect on the water surface. Zooplankton were present in Lake Granby in fairly large quantities and total counts ranged from 340 organisms per liter at the 120 foot depth at Station GB-8, to 1030 organisms per liter in the surface waters at the same station. The number of crustacea were quite high and these are important as preferred food organisms for fish life.

B. Taylor Park Reservoir

1. Temperature and Dissolved Oxygen

1. The temperature and dissolved oxygen patterns and stratification phenomena found in Taylor Park Reservoir were in many but not all respects quite similar to those conditions experienced in the study of Lake Granby. Field results for temperature and dissolved oxygen derived from investigations of Taylor Park Reservoir are shown respectively in Tables VI and VII. These results expressed as an average for Stations T-1, T-3 and T-5 in respect to depth are given in Figure 10. The three above stations were considered to be key sampling locations since greatest sampling depths were obtained at these points. Dissolved oxygen saturation values as an average for the three key stations in relation to depth are shown for Taylor Park Reservoir in Figure 11.

As in the case of Lake Granby little variation in temperature and dissolved oxygen was noted at the various lake stations for equal sampling depths. At first appearance the temperature data from Taylor Park Reservoir seems to be almost identical to that for Lake Granby. However, the results upon further analysis indicate that the temperature and dissolved oxygen gradients in the region of thermocline in Taylor Park Reservoir were less pronounced than in Lake Granby. The transition zone extending from 25 to 50 feet in depth in Taylor Park Reservoir demonstrated an average temperature gradient from the 25 to 50 foot depths of 0.9°C per meter and the maximum gradient from 25 to 40 feet was 1.1°C per meter of depth. As previously explained, a thermocline is considered to be present if the temperature gradient is equal to, or greater than 1.0°C per meter depth. The temperature pattern as observed in August 1962 for Taylor Park Reservoir indicates that existing stratification was a borderline condition at that time and furthermore is probably of little consèquence earlier or later in the season. For purposes of analyzing the field data, three zones of circulation separated by forces of relatively weak magnitude are presumed to exist in the reservoir. It was noted earlier that stratification in Lake Granby was only slightly greater in degree of intensity.

The waters of the upper 25 feet of Taylor Park Reservoir, which constituted the epilimnion zone, were relatively high but also uniform in temperature and dissolved oxygen content. Average temperatures in this region were somewhat lower than Lake Granby and ranged from 14.0 to

TABLE VI
Taylor Park Reservoir - Water Temperature (°C)

Depth (ft.)	Lake Stations							
	T-1	T-2	T-3	T-4	T-5	T-6	T-7	T-8
0	15.1	15.2	14.9	15.3	16.0	17.0	15.0	15.9
5	15.1	15.1	14.7	15.1	15.7	16.7	15.2	15.3
10	15.1	15.1	14.7	15.1	14.9	15.2	15.0	15.2
20	15.1	15.0	14.5	14.9	14.7	14.9	14.7	14.2
25						14.0	14.0	
30	13.1		11.5	11.0	12.0			12.2
40	8.8		9.0	7.3	9.0			
50	7.6		7.8	6.8	8.0			
60	7.2		7.0		7.4			
70	6.9		6.7		7.0			
80	6.8		6.3		6.9			
90	6.7		6.1		6.8			
100	6.5		6.0		6.6			
110	6.4		5.9					
120	6.2							
130	6.1							
140	6.1							

Depth (ft.)	Inflow and Outflow Stations			
	T-9	T-10	T-11	T-12
Surface	14.9	15.2	15.0	8.0

TABLE VII
Taylor Park Reservoir - Dissolved Oxygen (mg/l)

Depth (ft.)	Lake Stations							
	T-1	T-2	T-3	T-4	T-5	T-6	T-7	T-8
0	7.3	7.1	7.2	7.3	7.4	7.5	7.5	7.1
5	7.3							7.2
10	7.5	7.2	7.5	7.1	7.3	7.2	7.4	7.1
20	7.4	7.2	7.2	7.3	7.6	7.0	7.1	7.1
30	6.4		7.1	7.5	6.5			7.0
50	6.2		6.1	5.9	6.1			
70	6.1		6.3		6.2			
90					5.9			
100	6.1		6.2					

Depth (ft.)	Inflow and Outflow Stations			
	T-9	T-10	T-11	T-12
Surface	7.5	7.3	7.3	7.4

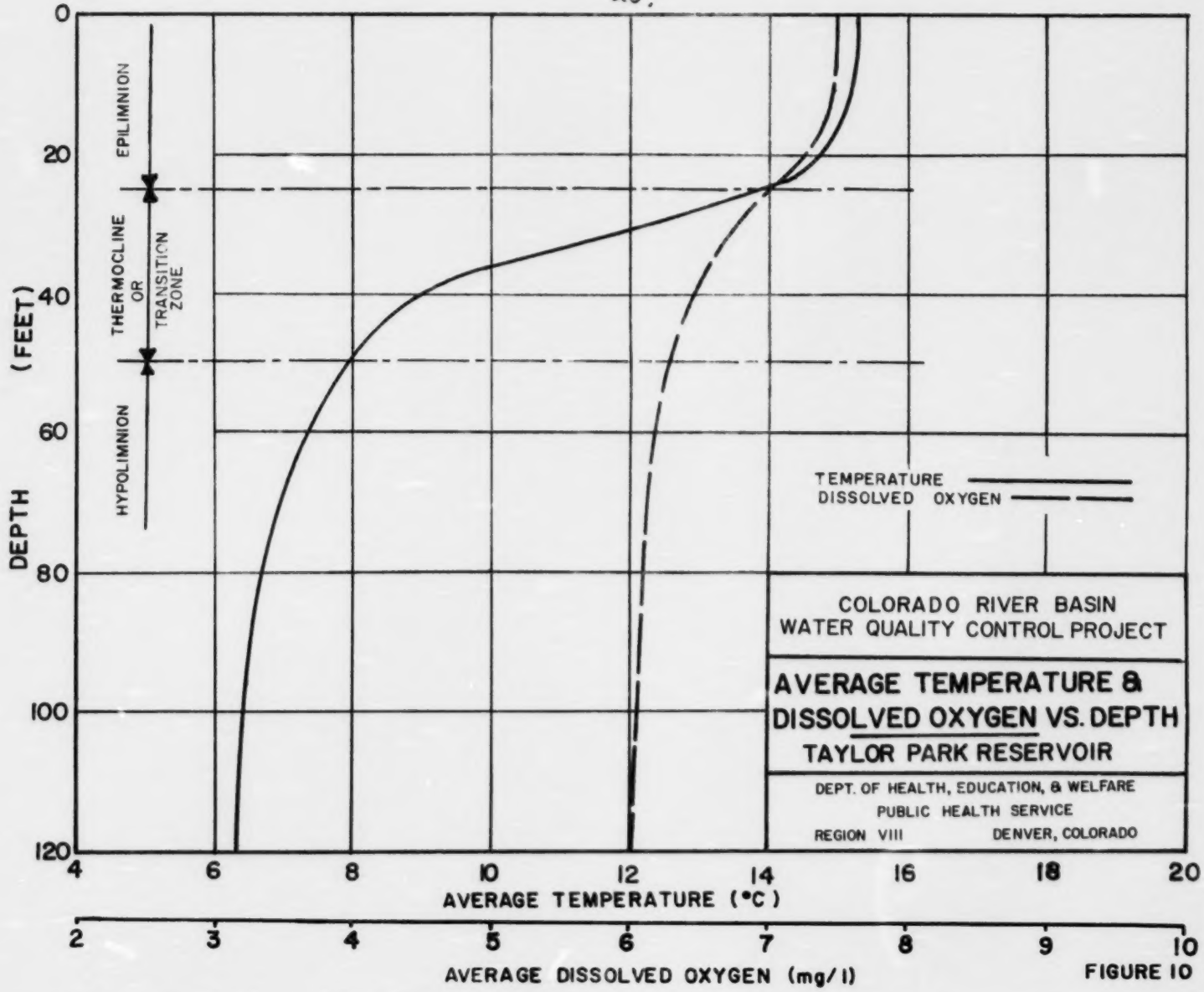

0
20
40
60
80
100
120
DEPTH (FEET)
EPILIMNION
THERMOCLINE OR TRANSITION ZONE
HYPOLIMNION
TEMPERATURE
DISSOLVED OXYGEN
COLORADO RIVER BASIN
WATER QUALITY CONTROL PROJECT
AVERAGE TEMPERATURE & DISSOLVED OXYGEN VS. DEPTH
TAYLOR PARK RESERVOIR
DEPT. OF HEALTH, EDUCATION, & WELFARE
PUBLIC HEALTH SERVICE
REGION VIII DENVER, COLORADO
4 6 8 10 12 14 16 18 20
AVERAGE TEMPERATURE (°C)
2 3 4 5 6 7 8 9 10
AVERAGE DISSOLVED OXYGEN (mg/l)

FIGURE 10

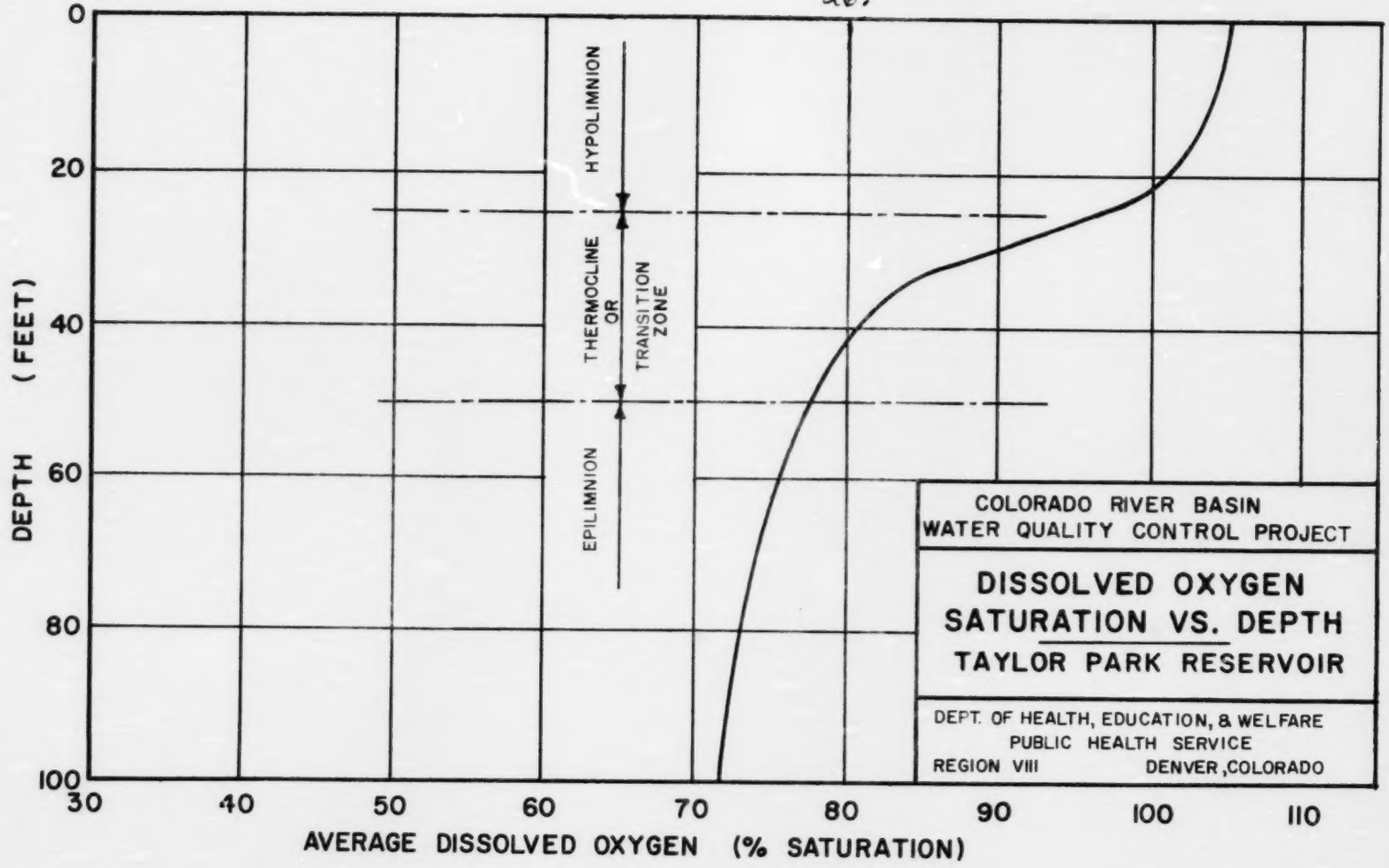


FIGURE II

GPO 837-924

15.3°C and average dissolved oxygen values were slightly less and ranged from 7.1 to 7.4 mg/l. Dissolved oxygen values were of lower saturation than Lake Granby waters and were between 94 and 101 percent of the saturation value.

The hypolimnion in Taylor Park Reservoir is considered to have extended from the 50 foot depth to the lake bottom. These lower waters exhibited ranges in temperature and dissolved oxygen content of 6.1 to 7.8°C and 6.0 to 6.2 mg/l. There is essentially no change of dissolved oxygen content below the 50 foot depth. It is noted that hypolimnion waters of Taylor Park Reservoir approximate Lake Granby waters in temperature but are somewhat higher in dissolved oxygen values. Dissolved oxygen levels in the hypolimnion of Taylor Park Reservoir range from 67 to 70 percent of the saturation value.

The thermocline region of Taylor Park Reservoir was discussed above. The weak stratification pattern existing in this zone is mentioned once again. Average temperatures of waters in the transition zone varies from 7.8 to 14.0°C and dissolved oxygen content ranged from 6.2 to 7.1 mg/l. Dissolved oxygen content in the thermocline zone was between 70 and 94 percent of saturation.

The various inflows into Taylor Park Reservoir including Taylor River (Station T-9), Texas Creek (Station T-10), and Willow Creek (Station T-11) were all comparable to surface waters in the reservoir in respect to temperature and dissolved oxygen values. The outflow from Taylor Park Reservoir was actually sampled 0.3 miles downstream from the Dam (Station T-12). The low temperature of this water (8.0oC) shows that there was a low level of withdrawal from the reservoir. The dissolved oxygen content (7.4 mg/l) of this water at Station T-12 indicates a significant pickup of oxygen in the turbulent stretch of stream below the Dam.

2. Biochemical Oxygen Demand

Individual results of BOD content of Taylor Park Reservoir waters are shown in Table IX of Appendix A. Levels of BOD in these waters were extremely low. Lake samples averaged 0.4 mg/l BOD with a range of 0.1 to 0.9 mg/l. The upper level of lake waters may have a slightly higher BOD content than the bottom lake waters although this difference was very small. Taylor River, Texas Creek, and Willow Creek inflows were comparable in BOD value to the lake proper whereas the outflow from Taylor Park Reservoir Dam had a BOD content of 1.8 mg/l.

The BOD data collected during the Taylor Park Reservoir study indicates little or no depletion of dissolved oxygen content of lake waters because of an extremely low level of organic material present. Biochemical conditions were similar to those experienced in Lake Granby. Taylor Park Reservoir may also be termed to be oligotrophic in nature.

3. Other Physical and Chemical Conditions for Taylor Park Reservoir

Field results for conductivity, alkalinity, pH, and Secchi Disk readings for the Taylor Park Reservoir study of August 1962 are shown in Table IX of Appendix A.

This data illustrates that conditions in Taylor Park Reservoir were in many respects similar to that found for Lake Granby. As in the case of Lake Granby, there was little or no variation of total dissolved solids and alkalinity content of waters throughout Taylor Park Reservoir. These values approximated 60 mg/l for total dissolved solids (conductivity = 84 μmhos/cm) and 32 mg/l for alkalinity. Total dissolved solids and alkalinity of Taylor River inflow (Station T-9) and outflow (Station T-12), and of Texas Creek (Station T-10) were about the same level as in the lake body. Willow Creek inflow contained approximately 130 mg/l dissolved solids and 29 mg/l alkalinity.

Very few pH values were obtained for waters of Taylor Park Reservoir. There is indicated a slight decrease in pH of lake waters with increase in depth. Levels of pH ranged from 8.1 to 8.6. Secchi Disk readings were considerably greater for Taylor Park Reservoir as compared to Lake Granby and indicated a higher capacity for light penetration and greater transparency of waters in the former lake. Secchi Disk values for Taylor Park Reservoir ranged from 18.5 to 23.5 feet with an average of 21.5 feet.

4. Plankton Studies

The results of plankton analyses for samples collected from Taylor Park Reservoir are shown in Table XI of Appendix C. Moderate numbers of plankton organisms were present. Phytoplankton counts were higher in Taylor Park Reservoir as compared to Lake Granby whereas zooplankton numbers were less. Again there was little difference in density of plant and animal plankton between the surface and bottom waters. Total phytoplankton numbers in Taylor Park Reservoir ranged from 124 organisms per ml for the 90 foot depth sample at Station T-5 to a maximum of 1358 organisms per ml in the 103 foot depth sample at Station T-8. There was a considerable difference in the composition of the phytoplankton population between Taylor Park Reservoir and Lake Granby. The waters of Lake Granby as stated previously, contained moderate numbers of blue-greens, diatoms, and greens but very few flagellates. Taylor Park Reservoir waters in contrast, contained a large preponderance of flagellate forms, low to moderate numbers of diatoms and very few blue-green and green algae. The flagellates consisted mostly of the genus Dinobyron, a relatively severe taste and odor producer in drinking water supplies. The majority of diatoms were determined to be Asterionella and Cyclotella.

Zooplankton densities in Taylor Park Reservoir varied from 45 organisms per liter in the surface waters at Station T-5 to 650 organisms per liter in the surface waters at Station T-9. Protozoa were present in largest numbers and levels of rotifers, nematodes, and crustacea were relatively low.

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APPENDIX A

PHYSICAL AND CHEMICAL DATA FOR LAKE GRANBY AND TAYLOR PARK RESERVOIR

August 1962

APPENDIX A

TABLE VIII
Physical and Chemical Data for Lake Granby
August 22-24, 1962

Station, Date & Time Sampled	Sample Depth (ft.)	Specific Conductance (μmhos/cm)	BOD (mg/l)	Alkalinity as $CaCO_3$ (mg/l)	pH
GB-1	0	<50	0.8	19	8.5
8-23-62	10	<50	0.6	-	-
1035	20	<50	-	18	8.3
	27 (bottom)				
Secchi Disk: 13 ft.					
GB-2	0	50	0.8	-	8.9
8-23-62	50	51	-	-	-
1100	80	55	-	-	7.9
	89 (bottom)				
Secchi Disk: 12 ft.					
GB-3	0	50	0.9	19	8.7
8-23-62	50	52	0.4	-	-
1135	105	55	0.5	22	7.7
	119 (bottom)				
Secchi Disk: 14 ft.					
GB-4	0	50	1.2	20	8.8
8-23-62	60	52	-	22	7.6
1430	72 (bottom)				
Secchi Disk: 10 ft.					
GB-5	0	50	1.0	-	8.9
8-23-62	25	50	-	-	-
1520	50	50	0.5	-	7.5
	52 (bottom)				
Secchi Disk: 10 ft.					
GB-6	0	52	1.0	21	
8-22-62	20	50	-	-	
1415	50	53	0.3	-	
	75	-	0.6	-	
Secchi Disk:	100	56	0.4	22	
13 ft.	150	56	-	-	
	180	55	0.4	22	
	200 (bottom)				

APPENDIX A

TABLE VIII (Continued)

Station, Date & Time Sampled	Sample Depth (ft.)	Specific Conductance (μmhos/cm)	BOD (mg/l)	Alkalinity as $CaCO_3$ (mg/l)	pH
GB-7	0	50	1.0	22	8.8
8-23-62	45	50	0.4	-	7.6
1540	50(bottom)				
Secchi Disk: 9 ft.					
GB-8	0	50	1.0	20	
8-22-62	20	54	-	-	
1640	50	51	0.3	-	
	100	53	0.5	-	
Secchi Disk:	120	54	-	21	
11.5 ft.	140(bottom)				
GB-9	10	50	0.8	20	
8-22-62	20	50	0.7	-	
	50	57	1.0	21	
Secchi Disk: 10.5 ft.	72(bottom)				
GB-10	0	<50	0.9	20	
8-22-62	20	<50	0.7	-	
	50	53	-	-	
Secchi Disk:	75	55	-	22	
7.5 ft.	81(bottom)				
GB-11	Surface	<50	1.7	16	7.6
8-23-62					
GB-12	Surface	58	1.5	23	7.9
8-24-62					
GB-14	Surface	230	1.1	114	9.1
8-24-62					
GB-15					
8-24-62	Surface	54	0.2	25	9.3

APPENDIX A

TABLE IX
Physical and Chemical Data for Taylor Park Reservoir
August 15-16, 1962

Station, Date & Time Sampled	Sample Depth (ft.)	Specific Conductance (μmhos/cm)	BOD (mg/l)	Alkalinity as $CaCO_3$ (mg/l)	pH
T-1	0	80	0.5	32.5	
8-15-62	10	80	-	32	
1355	20	85	0.3	32	
	30	85	-	31.5	
Secchi Disk:	50	80	0.4	32	
21 ft.	70	80	-	31	
	100	85	-	31	
	142 (bottom)				
T-2	0	80	0.5	31	
8-15-62	10	-	0.2	-	
1655	20	80	0.2	32	
	23 (bottom)				
Secchi Disk: 21 ft.					
T-3	0	85	0.3	32	
8-16-62	50	85	0.3	31	
0845	100	90	0.1	31	
	110	90	0.2	31	
Secchi Disk:	112 (bottom)				
23.5 ft.					
T-4	0	85	0.6	32	8.6
8-16-62	30	85	0.4	32	-
1600	50	85	0.4	32	8.6
	52 (bottom)				
Secchi Disk: 20.5 ft.					
T-5	0	75	0.5	33	
8-16-62	50	65	0.2	31	
0940	90	80	0.3	32	
	103 (bottom)				
Secchi Disk: 23 ft.					
T-6	0	90	0.3	32	
8-16-62	20	90	0.5	32	
1040	27 (bottom)				
Secchi Disk: 23.5 ft.					

APPENDIX A

TABLE IX (Continued)

Station, Date & Time Sampled	Sample Depth (ft.)	Specific Conductance (μmhos/cm)	BOD (mg/l)	Alkalinity as $CaCO_3$ (mg/l)	pH
T-7	0	85	0.4	31	
8-16-62	20	85	0.3	32	
1205	26(bottom)				
Secchi Disk: 18.5 ft.					
T-8	0	85	0.6	34	8.6
8-15-62	10	90	-	32	8.7
1115	20	85	-	32	8.4
	30	100	0.9	34	8.1
Secchi Disk: 22.5 ft.	33(bottom)				
T-9	Surface	90	0.3	33	
8-16-62					
1540					
T-10	Surface	60	0.1	29	
8-16-62					
1615					
T-11	Surface	180	0.4	10	
8-16-62					
1650					
T-12					
8-16-62	Surface	90	1.8	29	
1735					

APPENDIX B

MECHANICS OF PHYSICAL AND CHEMICAL STRATIFICATION IN LAKES AND RESERVOIRS

(A Discussion)

APPENDIX B

MECHANICS OF PHYSICAL AND CHEMICAL STRATIFICATION IN LAKES AND RESERVOIRS (7)

The forces of solar radiation and wind produce in most lakes and reservoirs a seasonal phenomena known as thermal stratification. Water has the property of increasing density with decreasing temperature downward to a temperature of 4°C or 39.2°F at which temperature it attains maximum density (s.g.=1.0). Below 4°C, water decreases in density with decreasing temperature until reaching the freezing point and formation of ice at 0°C or 32°F. The difference in density between two layers of water is known as thermal resistance and this difference is proportional to the force required to admix the two layers of water. Wind is the primary force in mixing the various layers of water within a lake or reservoir, this force being applied at the water surface. Solar radiation also applied at the surface of a water body heats the surface layers. Heat is transferred downward by convection currents and currents induced by wind action until thermal resistance at a particular level is of sufficient magnitude to prevent further mixing and transfer of heat from above. A transformation takes place where the warmer and freely-circulating upper waters become a floating and distinct body overlaying a cooler and relatively stagnant water body. These two zones, respectively the epilimnion and hypolimnion are separated by a transition zone generally termed the thermocline in which there are steep temperature and water density gradient constituting an effective barrier against wind mixing and isolating the lower water body from the upper.

The annual cycle of events normally experienced in most lakes and reservoirs in the United States is given as follows. This description will begin arbitrarily with the spring overturn.

During the latter part of winter, immediately preceding the disappearance of ice cover on a lake, a series of temperature readings at various depths will show the water near the surface under the ice cover is near the freezing point. At progressively greater depths, the water becomes gradually but slightly warmer. Surface water temperatures will approximate 0°C and the bottom waters will have temperatures around 4°C. Thus, the colder but lighter (less dense) waters will overlay the warmer but heavier waters.

Soon after the ice cover is dissapated, the surface waters are warmed to maximum density at 4°C and this heavier water overlaying lighter water (<4°C) subsides to the lower levels of the lake. Equal temperatures or water densities are established throughout the lake by this action. Since there is little resistance to mixing, the spring winds circulate these waters from top to bottom producing the phenomena known as the spring overturn or spring circulation. During early spring the heating process is slow and because at this time of the year thermal resistance is small, warmer water from the surface may be forced even to the bottom of the water body.

As spring continues, the rate of heat intake by surface waters exerts a greater force towards stratification than the ability of the winds to mix the waters of various depths. Thus, differences of thermal resistance of increasing magnitude at various horizontal levels are experienced. The formation of a definite stratification pattern to prevent mixing throughout the entire water mass marks the end of the spring overturn.

The surface waters continue to increase in temperature as solar energy increases. Wind action continues to provide full circulation of the upper zone in a lake but below this level there is formation of a narrow zone of steep temperature gradient separating the upper waters of relatively high temperature and the lower waters with temperatures approximating near winter conditions. The freely circulating upper layer with lower density and high temperature is known as the epilimnion. The stratum of rapidly changing conditions next below is known as the thermocline. The lowermost region which has remained more or less unchanged by the recent interplay of forces at the water surface is known as the hypolimnion. These bottom waters have very low temperatures and near maximum density.

The complete transition from spring overturn to thermal stratification may require many days or even weeks as the force of solar energy progressively increases and finally becomes of sufficient magnitude to restrict the force of wind action in complete mixing. As the summer continues, stratification becomes more intense and may also move upward in the reservoir thereby reducing the zone of the epilimnion. In early fall as stratification begins to weaken, the thermocline may subside to lower levels in the reservoir.

Concurrent with thermal stratification there is a transformation of chemical conditions within a lake or reservoir. Dissolved oxygen content in the epilimnion is near saturation unless greatly modified by photosynthesis and respiration of algae in the upper zone. Waters of the hypolimnion region do not receive benefit of reoxygenation for an extended period of time and there is a progressive decrease in oxygen content of the lower waters. Within the hypolimnion, oxygen demand is exerted by organic material present before the onset of stratification including the rich bottom muds of the reservoir itself, to which is added the continuous rain of plant and animal nonviable detritus from above sinking to the depths of the reservoir and also respiration of zooplankton and even phytoplankton that exist in this region. It is not uncommon that dissolved oxygen levels less than 2 mg/l may be found throughout the hypolimnion and the lowermost waters may even be completely devoid of oxygen. Anaerobic conditions are accompanied by the release of gases of decomposition including carbon dioxide, methane, and hydrogen sulfide. These gases may be found in extremely large concentrations near the lake bottom during late summer if there is intense decomposition. An increase in concentration of total dissolved solids, acidity, alkalinity, organic material, and various minor elements, and decrease in pH values are expected under these conditions. It should be noted in this brief discussion of summer stratification, that uniformity in chemical water

quality is generally established upon the advent of fall overturn at all levels in a lake. If fall overturn is not completely effective in mixing then spring overturn should provide these conditions of uniformity.

When thermal stratification is permanent, the lake or reservoir is in the summer stagnation period. This period extends through the summer and generally into the early part of autumn. Declining air temperatures, first at night and then throughout the day, begin to cause a cooling of the surface waters of a lake. This cooling continues attendant with mixing in the epilimnion until the upper zone attains the same temperatures as the upper part of the thermocline and later approximates temperatures of the hypolimnetic waters. Thereafter, the whole lake becomes homothermous and the wind can circulate lake waters from top to bottom. This condition is known as the fall overturn. In some of the deeper reservoirs in the southern and southeastern United States, this overturn in many years may not be complete and extend only to certain depths within the hypolimnion.

Essentially, the fall overturn is a repetition of the spring overturn with the significant difference being that the former is terminated by decreasing air temperature and not by increasing temperatures. Fall overturn continues until the winter stagnation period. Decreasing air temperatures in early winter lower surface water temperatures below 4°C and ice cover eventually forms. This marks the beginning of the winter stagnation period. The water immediately below the ice cover is near the freezing point and a short distance below there is a temperature rise up to about 3°C. Thence, there is a progressive but slight increase in water temperature to the lake bottom. The annual cycle in lakes and reservoirs then starts anew as described in the beginning of this discussion.

An oligotrophic lake is one which has low nutrient level and generally minimal algae growth. Low biochemical oxygen demand in these waters does not cause a serious depletion of oxygen resources. When a lake receives sewage or wastewater, additional nutrient cause eutrophication of the lake whereby the growth of plant material increases and oxygen levels in the lower waters will decrease. The eutrophic lake is well provided with nutrients for growth of plant and animal life and is frequently marked by drastic oxygen depletion of hypolimnetic waters during the summer stratification period.

APPENDIX C

RESULTS OF PLANKTON ANALYSES FOR LAKE GRANBY AND TAYLOR PARK RESERVOIR

August 1962

APPENDIX C

TABLE X
Results of Plankton Analyses for Lake Granby
August 22-24, 1962

		Phytoplankton (organisms/ml)					Zooplankton (organisms/liter)				
Station	Depth	Diatoms	Greens	Blue-greens	Flagellates	Total	Protozoa	Rotifers	Crustacea	Nematodes	Total
GB-3	Surface	12	32	159	6	209	305	30	40	0	375
"	105 ft.	479	7	18	0	504	420	0	360	0	780
GB-5	Surface	35	34	124	8	201	260	250	110	0	620
"	50 ft.	80	11	6	6	103	280	110	180	0	570
GB-6	Surface	104	36	140	23	303	220	260	130	0	610
"	185 ft.	81	6	6	0	93	160	20	640	0	820
GB-8	Surface	19	57	100	14	190	860	110	60	0	1030
"	120 ft.	51	0	20	0	71	170	40	130	0	340
GB-10	Surface	19	30	136	23	208	160	200	110	0	470
"	75 ft.	394	25	9	11	439	140	20	720	0	880

APPENDIX C

TABLE XI

Results of Plankton Analyses for Taylor Park Reservoir
August 15-16, 1962

		Phytoplankton (organisms/ml)					Zooplankton (organisms/liter)				
Station	Depth	Diatoms	Greens	Blue-greens	Flagellates	Total	Protozoa	Rotifers	Crustacea	Nematodes	Total
T-1	Surface	33	1	3	694	731	255	0	10	10	275
"	120 ft.	192	16	0	128	336	20	0	50	0	70
T-2	Surface	24	1	3	603	631	105	15	45	0	165
"	20 ft.	39	2	0	523	564	170	110	10	10	300
T-4	Surface	36	0	1	708	745	380	10	50	0	440
"	50 ft.	26	1	1	222	250	290	20	10	0	320
T-5	Surface	21	1	2	383	407	35	10	0	0	45
"	90 ft.	52	1	1	70	124	145	5	15	0	165
T-8	Surface	36	0	2	483	521	125	10	10	0	145
"	30 ft.	103	2	7	1246	1358	300	0	20	0	320
T-9	Surface	42	43	95	25	205	510	70	70	0	650
"	50 ft.	467	27	16	18	528	240	20	200	0	460